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AN ABSOLUTE TOTAL RADIATION RADIOMETER FOR MEASURING A WIDE RANGE OF IRRADIANCES IN SPACE SIMULATORS

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INTRODUCTION

The Jet Propulsion Laboratory has developed a radiometer designated MK IV which is especially suited for use in space chambers for measuring a wide range of simulated solar irradiances during tests of spacecraft. The radiometer is now in use in several space chambers in both USA and in Europe. The MK IV is a further development of the radiometers described in references 1 and 2.

The MK IV radiometer has an absolute accuracy of ± 0.5% and is self-calibrating. On this account it is not necessary to compare the MK IV with any other standards, since it itself can very well serve as a primary standard. It has uniform responses over the entire spectrum, uv, visible, and on into the far ir. Furthermore, measurements can be made with the stated accuracy of 0.5% throughout a range of irradiances of about 0.1 KW/M^2 up to 42 KW/M^2 (30 solar constants). The radiometer performs equally well in the environment of the space chamber under high vacuum with LN_2 chilled shrouds, or in normal room environment at 25^oC and 1 atmosphere pressure. It is generally used without a window on the radiometer. Of course, should it be desired to use a window, it is then necessary to make the necessary allowances for the effect of the window on the response.

DESCRIPTION OF THE RADIOMETER

Figure 1 is a photograph of the radiometer, and Figure 2 is a sketch showing the cross section. The most essential part of the radiometer is the internally blackened cavity which constitutes a small blackbody. Thermally connecting the cavity to the main body of the radiometer is a thermal resistor, which conducts heat produced in the cavity to the main body, whose temperature is held constant either by water of constant temperature flowing through the tubular coil around the main body, or else by the controlled electrical heating of the main body. The temperature drop across the thermal resistor (measured by a thermopile), serves as a measure of heat flux through the thermal resistor of the heat produced by the incoming irradiance, or produced by the calibrating electrical heater built into the cavity. When the current and voltage fed to the calibrating heater are accurately measured, this heater produces heat which is accurately equivalent to that produced by incoming irradiance so that, together with the thermopile response, a means is available for obtaining an accurate calibration of the radiometer without making a comparison to any other standard. This is why the MK IV can itself be considered as a primary standard.

An electronic control unit has also been developed. With the built-in DVM, it gives a continuous readout in absolute values in selectable units of the irradiance being measured.

The radiometer is generally used without any window, which (except under special circumstances) can cause complications in interpreting measurement results.

The overall dimensions of the MK IV radiometer are 2 inches (51 mm) in diameter, and 3 inches (75 mm) long. The area of the aperture is very nearly 1 cm^2. The radiometer weighs 0.9 Kg.

CHARACTERISTICS

Basically, the accuracy of the radiometer depends on:

1. Area of the aperture.
2. Electrical measurements of current and voltage to the calibration heater.
3. Effective absorptance of the cavity.

Measurements of area of the aperture, and measurements of current voltage are straightforward and present no difficulties. The effective absorptance of the cavity has been calculated. The black coating used inside the cavity has an absorptance of about 0.98, but the cavity enhancement of the absorptivity brings the overall effective absorptance up to 0.998. Since an allowance can easily be made for the 0.2% lack of perfect blackness, there is essentially no loss of accuracy from this cause.

With everything considered, measurements by the radiometer are within 0.5% of true values. This statement has been verified by using the radiometer to make an experimental determination of the Stefan-Boltzmann constant. (See Ref. 2). The value found was within 0.3% of the theoretical value of the Stefan-Boltzmann constant. This circumstance gives an indication of the accuracy of the MK IV.

Over the range of irradiances of 0.1 KW/M^2 to 42 KW/M^2, the MK IV is within 1.5% of being perfectly linear. This deviation can easily be measured by calibrating the radiometer at various levels throughout this range. The effect of this small non-linearity can easily be allowed for in measurements, so that the non-linearity does not introduce error.

When the temperature of the main body of the radiometer is held constant at some standardized value, the calibration of the radiometer remains constant. If the temperature is not held constant, then the radiometer sensitivity increases with increasing temperature through the variation of sensitivity of the chromel constantan thermocouples making up the thermopile. For example, if the water temperature varies 3^{o}C from the standardized value, the calibration constant of the radiometer is changed about 0.25%.

The 1/e time constant of the radiometer is between 7 and 8 seconds for a step change in irradiance. If the step change is large, like zero up to 1 solar constant from either irradiance or from calibration heating, then stabilization to 0.1% is attained after one minute.

RESPONSE IN DEPENDENCE ON VIEW LIMITING

Radiometers are frequently provided with view limiters, and the MK IV is no exception. However, the MK IV can be used without a view limiter, or on the other hand, it can be view limited to as small an acceptance angle as desired. For use in space chamber, it is generally desirable not to view limit the radiometer too much. The radiometer should at least be capable of viewing the mirror in the space chamber, and certainly must have an acceptance angle which is considerably wider than the angels due to lack of collimation and divergence of the beam.

Figure 3 shows three different responses of the MK IV with three different amounts of view limiting and Figure 4 shows how the angle ϕ is to be taken. Curve 1 shows the angular response with no view limiting (so called 180^o setup). Curve 2 is with the normal view limiting used in the JPL space chamber. In this case the viewing angle is about 80^o. Curve 3 shows a response with a view limiter giving about 40^o. It is to be noted that even the 180^o arrangement has considerable directivity. In other words, such a radiometer has by far most of its response in the general direction in which it is aimed. It sees very little to the sides, and, of course, nothing in the opposite direction. A more restricted view limiting simply accentuates the directivity, resulting in less response to off-axis irradiances.

For space chamber work, any degree of view limiting from 180^o down to 40^o (see Figure 3) apparently can give satisfactory results. In other words, the degree of view limiting above a certain value is not very critical.

Generally, as shown in Figure 5, the radiometer is mounted in the space chamber with its axis aimed at the simulated solar source, and it is located enough ahead of the spacecraft under test so that the radiometer will not "see" any of the spacecraft. Then irradiances from the LN_2 cooled shrouds on the sides and below or behind (if in a horizontal space chamber) the spacecraft, as well as any "hot spots" in the chamber will not enter into the measurement by the radiometer. Fortunately, in a properly designed space chamber, the magnitude of these effects is quite small, of the order of a couple milliwatts/cm^2. Hence, only a rather crude estimation of their magnitude is usually sufficient for making an allowance for these effects. On the surfaces of the spacecraft facing the simulated solar source, no correction to the irradiance measurement is made, since it is assumed that the radiometer has measured the sum total of irradiances from the simulated solar source and from stray effects from the mirror, and the neighboring areas.

TARE

When no irradiance is applied to a radiometer, one would expect the radiometer would give a zero indication. As anyone who has made measurements with radiometers well knows, zero applied input seldom gives zero indication. In other words, with zero applied irradiance, there is a definite indication of input. This anomalous indication is frequently referred to as tare. If tare is not correctly taken into account, a serious degredation fo the measurement accuracy can result. Hence, tare phenomena are very important and deserve to be carefully considered.

Tare does not usually represent an imperfection in the radiometer, for tare can, and usually does occur, with every type of radiometer, except certain special conditions. With a total radiation radiometer, tare generally is observed when the temperature of the radiometer differs from the temperature of the surrounding environment. As long as the radiometer and environment are above absolute zero temperature ($0^{o}K$), infra-red radiation to which the radiometer responds is very much present. The environment emits ir some of which finds its way into the aperture of the radiometer, and at the same time the radiometer is itself radiating ir. If, for example, the radiometer is at a different temperature than the environment, the radiometer will probably absorb a different amount than it is emitting, and hence will indicate a "tare" reading. If the radiometer is warmer than the environment, it will be emitting more radiation than it is receiving and will then indicate a negative tare. For the special case that the environment is everywhere at a uniform temperature and the radiometer is also at this same uniform temperature, then there is no net exchange of radiation between radiometer and environment. Under these conditions the tare is zero.

This condition for zero tare is approximated when the radiometer is in an ordinary room with everything (radiometer included) at a settled temperature. The tare is then small, being usually less than one milliwatt/cm^2. In the case of the radiometer in the space chamber, the conditions are far different when the space chamber is chilled by LN_2, and the radiometer is maintained at a constant temperature such as $25^{o}C$, the radiometer is emitting radiation characteristic of $25^{o}C$, but the chilled shrouds of the chamber are emitting almost no radiation. Hence the radiometer indicates a very large negative tare.

The magnitude of this tare is given by

$$\text{Watts/cm}^2 = A\varepsilon F_{1-2}\sigma(T^4_{walls} - T^4_{rad.})$$

where

Watts/cm^2 = watts/cm^2 (sometimes designated as W_L)

A = area of radiometer aperture in cm^2 = 1 cm^2

ε = emissivity (or absorptivity) of radiometer cavity ~ 1

F_{1-2} = view factor of radiometer. 0.36

σ = Stefan-Boltzmann constant. 5.6697×10^{-12}

T_{walls} = Kelvin temperature of space chamber shrouds. 80°K.

$T_{rad.}$ = Kelvin temperature of radiometer. 300°K.

Substituting the assumed numerical values given above, and applicable to the MK IV, in the above expression gives a tare of -0.016 watts/cm^2, which is 12% of one solar constant.

With a tare value of -0.016 watts/cm^2, a simulated solar irradiance of +0.016 watts/cm^2 must be provided in the space chamber to make the radiometer indicate zero. Hence, the correct intensity is arrived at only when W_L (in this case = +0.016 watts/cm^2) is added to the radiometer indication. In other words

$$W = W_{rad.} + W_L .$$

DIRECT READOUT CONTROL UNIT

Also developed at JPL is a direct readout control unit (shown in Figure 6) for use with the MK IV radiometer. The unit has a built-in DVM used for indicating values of irradiances measured by the MK IV radiometer. Also built into the control unit are all necessary circuits and controls for calibrating the radiometer and adjusting the circuits so that the readout of irradiance shown by the DVM is in one of the selected units of irradiance: KW/M^2, watts/cm^2, milliwatts/cm^2, watts/Ft^2, or in solar constants. An additional control makes it possible to allow for tare.

Making a calibration of the MK IV radiometer takes no more than two minutes. Once the radiometer is calibrated and the tare adjustment made, the DVM then continuously indicates the irradiance being measured. A BCD output from the DVM provides for continuous recording of the irradiance as a function of time.

CONCLUDING REMARK

The combination of the MK IV radiometer and the associated control unit provides an accurate and convenient means for making measurements of irradiance of total radiation. The MK IV radiometer has been in use in the JPL space chamber for several years, and has been used for monitoring simulated solar irradiances of all space crafts tested during this time.

REFERENCES

1. Kendall, J. M. Sr., Primary Absolute Cavity Radiometer, Technical Report 32-1396, Jet Propulsion Laboratory, Pasadena, Calif., July 1969.

2. Kendall, J. M. Sr., and Berdahl, C. M., "Two Blackbody Radiometers of High Accuracy," Applied Optics, Vol. 9, p. 1082, May 1970.

3. This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NAS 7-100, sponsored by the National Aeronautics and Space Administration.

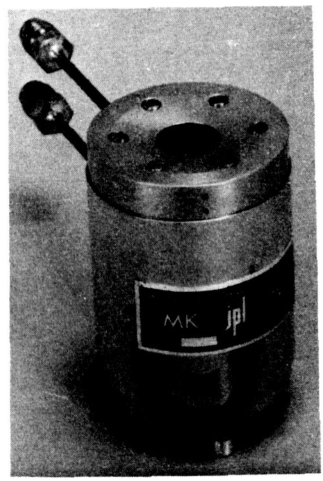


Fig. 1 - JPL MK IV Radiometer

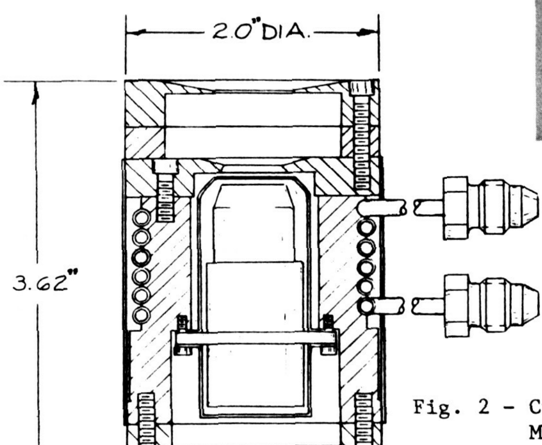


Fig. 2 - Cross section of the MK IV Radiometer

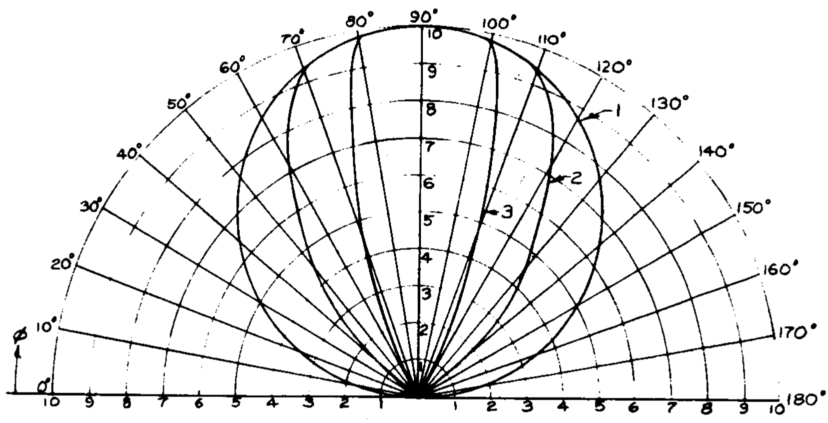
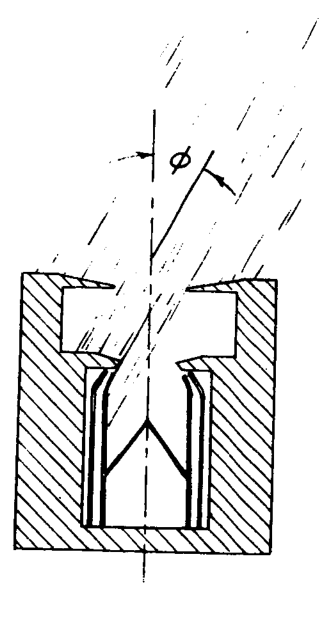


Fig. 3 - Relative response of the MK IV Radiometer with three different view limiters

1. - No view limiting (180^{o})
2. - View limiting as used in the JPL space chambers (80^{o})
3. - Smaller view limiting (40^{o})

Fig. 4 - Angle of Incedence ϕ



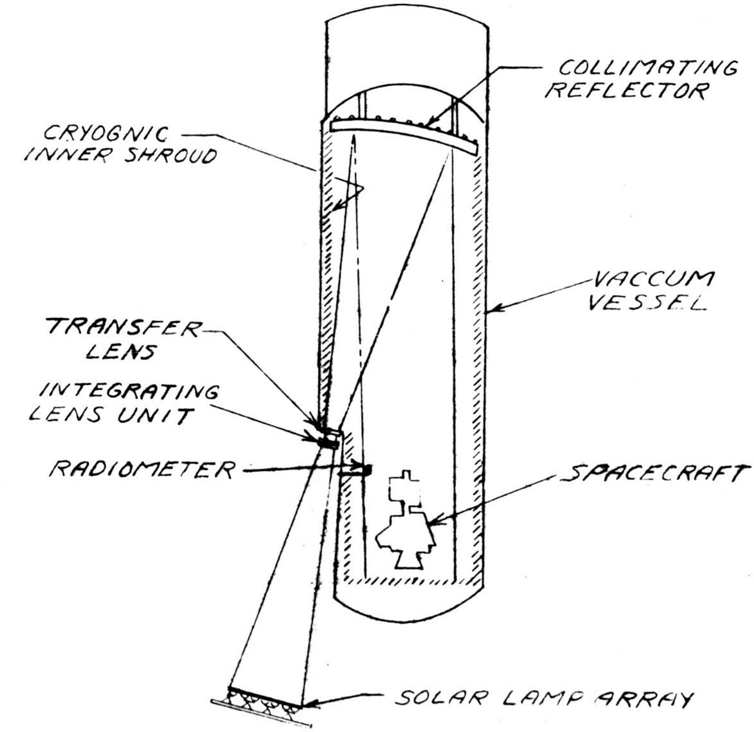


Fig. 5 - JPL Space Chamber, showing location of radiometer

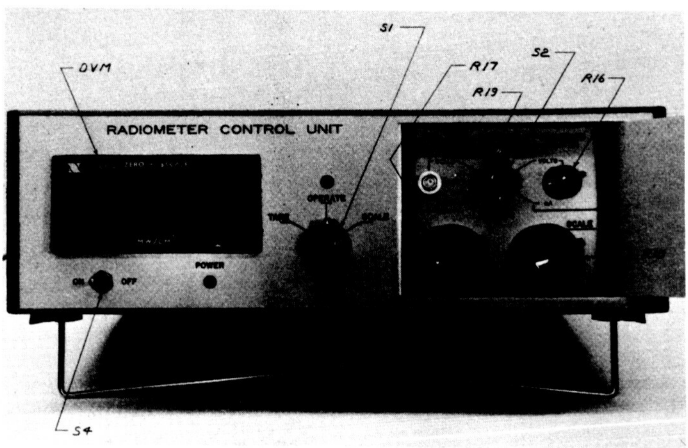


Fig. 6 - JPL Control Unit for use with the MK IV Radiometer